Numerical studies improve of flow around a wing with a pulling airscrew

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Received May 1, 2024
Revised September 30, 2024
Accepted October 30, 2024

The results of numerical investigations the improvements of flow around the straight wing using a vortex generator, which is located behind pulling airscrew are presented. Numerical studies were carried out using the numerical code for the Reynolds-averaged Navier–Stokes equations, on angle of attack $\alpha = 10^\circ$ with Much and Reynolds numbers $\mathrm{M} = 0.12$ and $\mathrm{Re} = 0.7 \cdot 10^6$

Keywords: aerodynamic characteristic, straight wing, vortex generator, pulling airscrew.

DOI: 10.61011/TP.2024.12.60427.334-24

With the development of computer technology, it has become possible to study the body flow of various aircraft models and their parts using numerical methods. Modern computational programs that take into account the effect of viscosity, given satisfactory convergence with the experiment is provided, make it possible to obtain the aerodynamic characteristics of the studied models and a detailed information about the investigated phenomenon. Mathematical modeling in various programs of a flying aircraft with an operating propeller demonstrates results close to the experimental [1,2] ones, therefore, in the numerical studies presented in this paper, the same computation technique with two air estimated zones was used.

The tractor propeller has a significant impact on the airflow over wing body and its aerodynamic characteristics. An important role is played by the velocity of the incoming flow, the number of blades, the angle of their installation and the diameter of the propeller. When there's blowing over the wing located in the wake of perturbation swirling flow from the tractor propeller it results in the change of pressure on its surface, and with an increase in the angle of attack, it leads to its interaction with the separation area increasing the size of this area [3].

The prevention or mitigation of undesirable phenomena associated with flow separation from the wing is critical in aerodynamic design of an aircraft. One of the ways to solve these problems is using vortex generators, which are special devices that create vortices to enhance the exchange of motion between the wall and the outer part of the boundary layer [4].

In this paper, a vortex generator was used, located on the upper surface of the wing in the propeller wake. The vortex generator forms an additional tangential velocity component, which weakens the negative transverse air flow over the wing upper surface. In addition, the effect of this vortex generator is enhanced via blowing from the propeller. Thus, the purpose of this paper is to study the stall control from a wing using a vortex generator. All computations were made experimentally in the wind tunnel [5] on a straight wing console with a symmetric profile NACA 642A015 [6], chord $b = 0.24\,\mathrm{m}$, wing area $S = 0.1594\,\mathrm{m}^2$, span of $L = 0.664\,\mathrm{m}$ and relative elongation $\lambda = 2.8$ (Fig. 1). The origin is located at the extreme point of the nose of the wing root profile attached to the wall of the working part of the wind tunnel. A four-bladed tractor propeller with a diameter of $\oslash = 0.23\,\mathrm{m}$, rotating clockwise when viewed from the front is located in the middle of the wing. The propeller has a rotation frequency of $N = 1000\,\mathrm{rpm} = 166.67\,\mathrm{Hz}$. Advance ratio $J = 1$, thrust coefficient at angle of attack $\alpha = T/(\rho_\infty n^2 D^4)$, where T — propeller thrust [N], ρ_∞ — air density [kg/m^3], n — propeller rotation frequency [Hz], D — propeller diameter [m].

A vortex generator located at an angle of 45° to the incoming flow was installed behind the propeller on the upper surface of the wing at a distance 60% from the end of the blade and 20% of the wing chord from the profile nose. The vortex generator has the shape of a plate about 13% long and 3% high of the wing chord.

Numerical analyses were performed using ANSYS FLUENT program, based on the solution of Reynolds-averaged Navier-Stokes equations, on structured computational grids with vortex generator and without vortex generator containing about $20 \cdot 10^6$ cells. To resolve the boundary layer, a special *o-grid* was created constructed along the normal to the surface and containing 20 cells in height. When modelling in the boundary layer region, the height of the first grid cell near the wing surface was chosen such that the boundary layer could accommodate a sufficient number of cells to calculate the near-wall function $y^+ = \frac{\rho \cdot u_\tau \cdot y_p}{\mu}$, where u_τ — characteristic velocity, y_p — distance from a point in space to the model wall, ρ — density, μ — air viscosity. For grids constructed in this way, the parameter $y^+ \leq 0.96$ characterizes the height of the first cell of the computational grid, calculated from the surface of

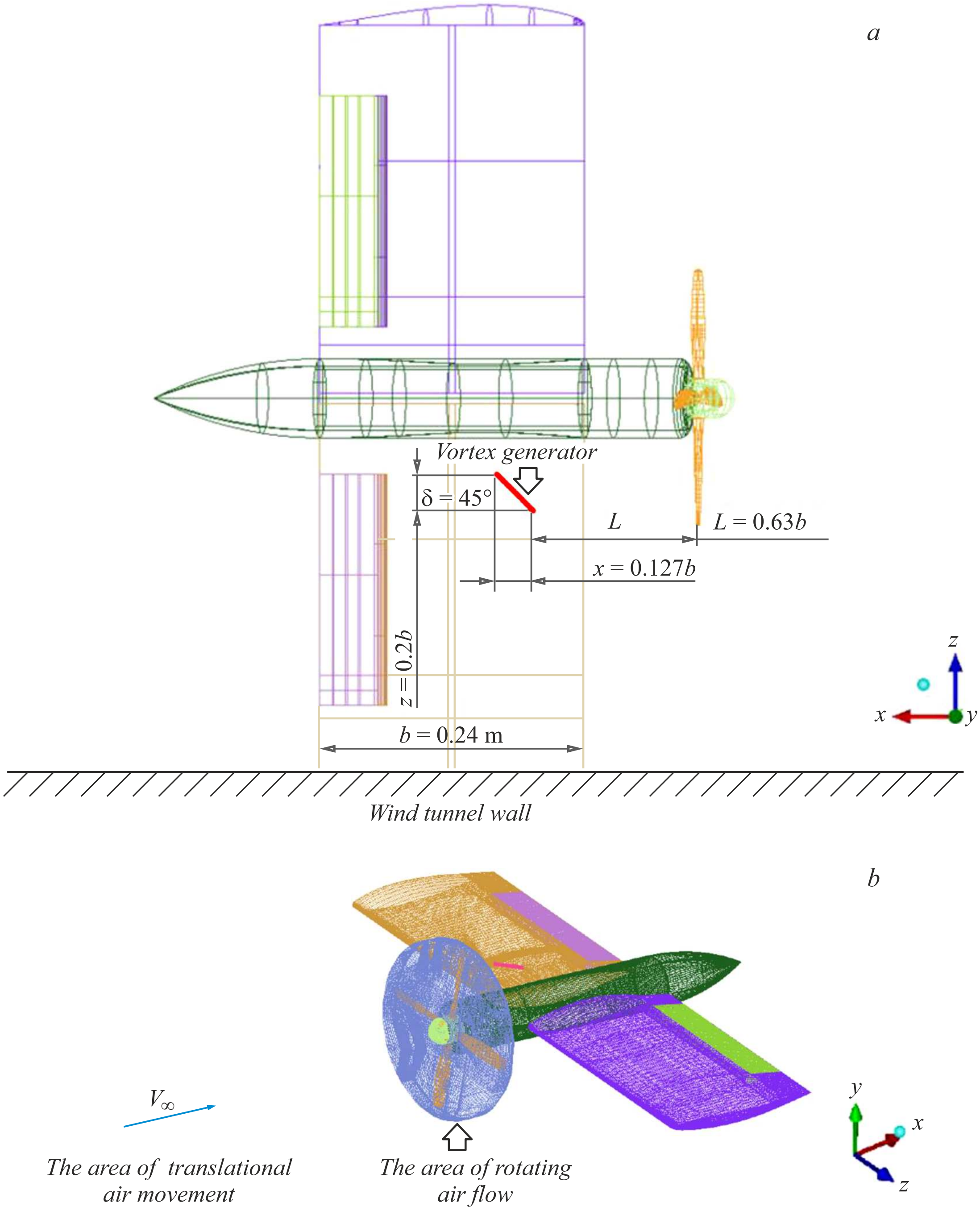

Figure 1. Computational wing model: *a* — general view, *b* — building of a computational grid.

the model, and corresponds to the recommendations of the program developers. The computations were made with *k-ε-realizable* turbulence model with improved modelling of turbulence parameters near the wall and taking into account the influence of pressure gradient. This turbulence model was selected because it makes fairly accurate predictions of boundary layer characteristics for large pressure gradients, breakaway and rotating flow currents. Additionally, *k-ε-realizable* turbulence model is appropriate for computations with a coarse grid with small amount of cells [7].

Table 1. Aerodynamic coefficients of the model, $\alpha = 10^\circ$, $\beta = 0$

Number of grid cells	$12 \cdot 10^6$	$20 \cdot 10^6$	$30 \cdot 10^6$
C_y	0.51224	0.53128	0.53384

Experiment: $C_y = 0.5367$

The computations were made based on the well-known procedure [1–3], with two computational areas:

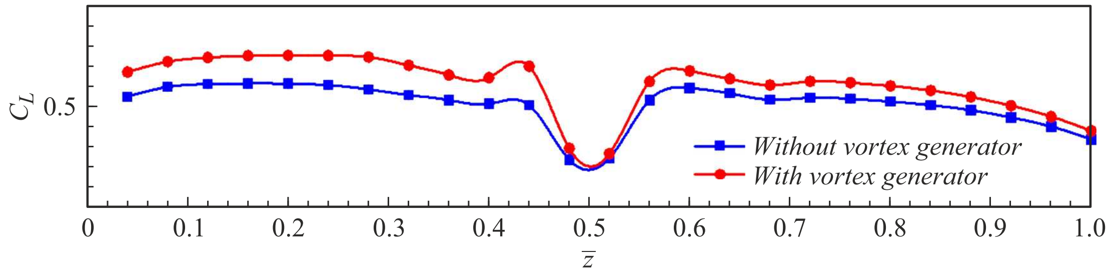

Figure 2. Distribution of the lift coefficient in wing sections.

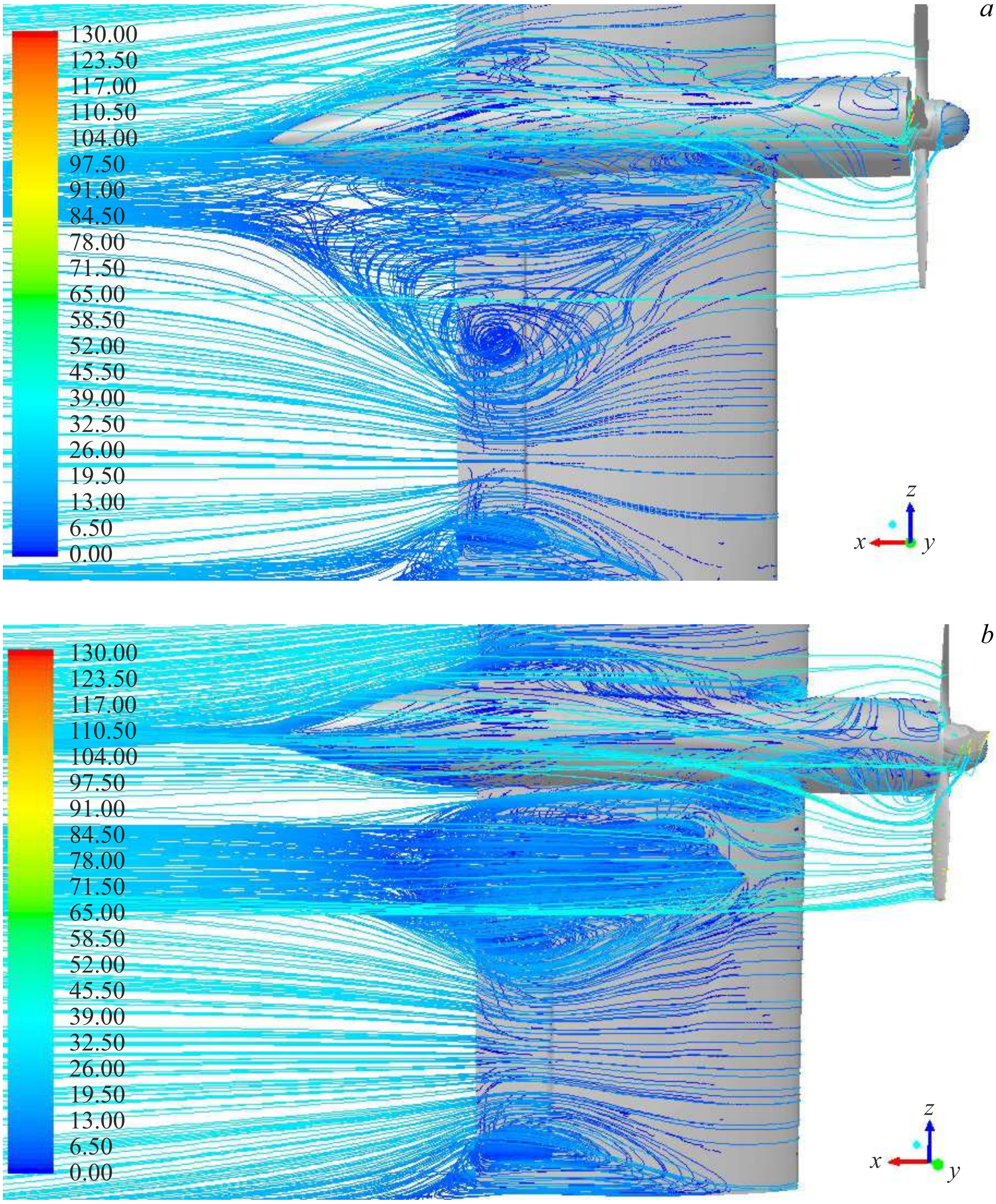

Figure 3. Cross-sectional velocities profile in the middle of the vortex generator: *a* — without vortex generator, *b* — with vortex generator.

Table 2. Calculation results

Wing	C_y	C_x	m_z	k
Without vortex generator	0.53128	0.12987	0.026435	4.09086
With vortex generator	0.63194	0.12254	0.022533	5.15701

1) with translational motion of air flowing over the studied wing model with a velocity of $V_\propto = 40$m/s;

2) with rotational motion of air around the propeller blades for modelling of its rotation (Fig. $1, b$).

Numerical studies were carried out at the numbers $\mathrm{M} = 0.12$ and $\mathrm{Re} = 0.7 \cdot 10^6$ at the angle of attack $\alpha = 10°$, when a flow stall forms on the wing.

In order to determine a sufficient number of computation cells for this task, computations were performed on various grids of the wing model aerodynamic characteristics for a wing with a propeller without a vortex generator (Table 1). As a result of the analysis of grid convergence data, a grid containing 20 million cells was selected as a computational grid.

The impact of the vortex generator on the lift coefficients in the wing sections was found by formula $C_{y\,sect.} = \frac{Y}{q_\infty b_{sect.}}$, where Y — wing section lift force, $b_{sect.}$ — wing chord, q_∞ — impact air pressure. The lift coefficients in 25 sections cut by XOY plane are shown in Fig. 2, respectively, depending on the relative wing semi-span $\overline{z} = z/L$, where z — coordinate for section L — span of wing, shown in Fig. 2. The vortex generator increases the air circulation over the wing, resulting in the enhanced lift.

According to the computation results, the vortex generator creates a vortex that favorably affects the flow around the wing in the propeller wake and reduces the size of the separation area (Fig. 3). At that, the separation area boundary moves back along the flow. So, in the cross-section in the middle of the vortex generator, it can be seen that the vortex generator pushes back the separation area, the beginning of which now coincides with the place of generator installation on the wing, and as a result, the resistance of the wing goes down. The computational results showed (Table 2) that the vortex generator increases the lifting force C_y, reduces the drag C_x, slightly increases the rearward pitching momentm_z and at the same time increases the aerodynamic quality k.

As a result of numerical analysis of a vortex generator located on a straight wing behind a tractor propeller, it is demonstrated that the vortex generator contributes to better airflow in the propeller wake, higher size of the separation area, higher lift and lower wing drag, while its effect is enhanced and stabilized by constant blowing from the propeller.

Conflict of interest

The authors declare that they have no conflict of interest

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Translated by T.Zorina